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$AF/2871

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re the Application of:	Group Art Unit: 2871
JUIZHI XUE, et al.	Examiner: Thoi V. Duong
Serial No.: 09/591,437	
Filed: June 9, 2000	
Atty. File No.: 50041-00037	
For: "CHEVRON-FREE FLC DEVICE"	

CERTIFICATE OF MAILING

I HEREBY CERTIFY THAT THE ORIGINAL ~~AND TWO COPIES~~ OF THIS CORRESPONDENCE IS BEING DEPOSITED WITH THE UNITED STATES POSTAL SERVICE AS FIRST CLASS MAIL IN AN ENVELOPE ADDRESSED TO COMMISSIONER FOR PATENTS, MAIL STOP: APPEAL BRIEF-PATENTS, ALEXANDRIA, VA 22313 ON DEC. 1, 2003.

MARSH FISCHMANN & BREYFOGLE LLP

BY: Terri Belich
TERRI BELICH

TRANSMITTAL OF APPEAL BRIEF

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450
MAIL STOP: APPEAL BRIEF - PATENTS

Dear Sir:

Enclosed please find in triplicate an "APPELLANT'S BRIEF ON APPEAL" for the above-identified patent application. Also enclosed please find a check in the amount of $330.00 as the fee for filing a brief in support of an appeal for a large entity under 37 CFR § 1.17(c). Please credit any overpayment or debit any underpayment to Deposit Account No. 50-1419.

Respectfully submitted,

MARSH FISCHMANN & BREYFOGLE LLP

By: Robert G. Crouch

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3151 South Vaughn Way, Suite 411
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Date: December 1, 2003

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MARSH FISCHMANN & BREYFOGLE LLP

BY: ~~TERRI BELICH~~ Robert Crouch

APPELLANTS' BRIEF ON APPEAL

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450
MAIL STOP: APPEAL BRIEF - PATENTS

Dear Sir:

The structure of Appellant's Brief is as follows and in the order required by 37 CFR § 1.192(c):

I. Real Party in Interest
II. Related Appeals and Interferences
III. Status of Claims
IV. Status of Amendments
V. Summary of Invention
VI. Issues
VII. Grouping of Claims
VIII. Arguments: Rejections under 35 USC § 102(e)
IX. Conclusion

Appendices

A. Claims involved in the Appeal.

B. A copy of U.S. Patent No. 6,141,076 to Liu et al.

C. A copy of passages from Ferroelectric and Antiferroelectric Liquid Crystals, by Sven T. Lagerwall (1999).

I. REAL PARTY IN INTEREST

The inventor of the above-noted patent application has assigned all respective rights in relation to the above-noted patent application, including any resulting patent, to Displaytech, Inc. a Colorado corporation with a place of business in Longmont, Colorado, in the Assignment that was recorded at the U.S. Patent Office ("PTO") on September 25, 2000 at Reel 011107, Frame 0500. Therefore, Displaytech, Inc. is the real party in interest in this appeal.

II. RELATED APPEALS AND INTERFERENCES (37 CFR § 1.192(c)(2))

Appellant, Appellant's legal representative, the assignee of the above-noted patent application, and the named inventors for the above-noted patent application are all unaware of any appeal(s) or interference(s) which will directly affect, be directly affected by, or have a bearing on the Board's decision in the pending appeal.

III. STATUS OF CLAIMS (37 CFR § 1.192(c)(3))

The status of the claims is as follows:

1. Claims pending: 1 - 26;
2. Claims rejected: 1 - 26; and
3. Claims appealed: 1 - 26.

IV. STATUS OF AMENDMENTS (37 CFR § 1.192(c)(4))

Applicant filed U.S. Patent Application No. 09/591,437 on June 9, 2000. The application contained 22 total claims, 3 of which (Claims 1, 13, and 14) were independent claims. Applicants received a first Office Action, mailed February 15, 2002, wherein Claims 1-22 were rejected under 35 U.S.C. 112, 2nd paragraph and under 35 U.S.C. 102(b) as anticipated by Bos (USPN 4,900,132). Applicant filed an Amendment and Response on June 17, 2002, amending Claims 1, 2, and 13-15.

Applicant received a second Office Action, mailed October 1, 2002, rejecting Claims 1-22 under 35 U.S.C. 102(e) as anticipated by Liu et al (USPN 6,141,076). On January 2, 2003, Applicant filed an Amendment and Response to Second Office Action, arguing distinctions in the claims as compared to Liu and adding new Claims 23-26, with Claims 25 and 26 being independent

A third and Final Office Action was mailed March 25, 2003, rejecting Claims 1-26 under 102(e) as anticipated by Liu et al (USPN 6,141,076). Applicants filed a Response to Final Office Action on May 27, 2003 requesting reconsideration in part based on the Final Office Action having logic that Applicants were unable to follow and, to the extent it could be followed, it seemed incorrect. There was no attempt to amend any claims after the Final Office Action. An Advisory Action was mailed on June 17, 2003 stating that the application was still not in condition for allowance and repeating the same logic that could not be understood.

A Notice of Appeal was filed by Applicants on September 25, 2003 and stamped as received by the PTO on September 29, 2003, making this Appeal Brief due November 29, 2003, or the first day thereafter on which the PTO is open (December 1, 2003).

V. SUMMARY OF INVENTION (37 CFR § 1.192(c)(5))

Generally, the present invention (Claim Group A defined in Section VII below) relates to an optical device 100 (Fig. 2 and page 5, line 15 through page 6, line 34) or system 300 (Fig. 4 and page 7, line 1 through page 9, line 16) (or a method for using same) that includes a ferroelectric liquid crystal material (10). The device includes a first and second substrate (32A and 32B in Fig. 2 and 332A and 332B in Fig. 4), with alignment treatments (110A and 110B in Fig. 2 and 310A and 310B in Fig. 4) applied to surfaces of the first and second substrate. The alignment treatment on each of the two substrates induces an orientation of at least a portion of the ferroelectric liquid crystal material therebetween along an alignment direction (page 5, line 29 through page 6, line 4). The first and second substrates are located relative to each other in such a manner that the first and second alignment directions are not aligned with each other, so that a non-zero angle Ω is formed between the projections of the two alignment directions on the two substrates (page 6, lines 5-9). Further, the claimed invention requires that the device is free of chevron structures (page 6, lines 24-34).

The invention of Claim Group B (described in Section VII below) includes the features described in the above paragraph plus a limitation that an optical retardance of the optical device remains generally constant during continuous variation of the optical state of the light output (page 8, lines 24-25 and page 9, lines 12-16).

The invention of Claim Group C (described in Section VII below) includes the features described in the first paragraph of this Section plus a limitation that the ferroelectric liquid crystal material is surface stabilized. (page 1, lines 5-33).

The invention of Claim Group D (described in Section VII below) includes the features described in the first paragraph of this Section plus a limitation that the first and second substrates are spaced apart by a distance sufficiently small to suppress formation of helixes typically formed in bulk of the ferroelectric liquid crystal material. (page 1, lines 22-25 and page 7, lines 17-25).

VI. ISSUES (37 CFR § 1.192(c)(6))

1. Are Claims 1–26 anticipated by Liu et al (USPN 6,141,076)?

VII. GROUPING OF CLAIMS (37 CFR § 1.192(c)(7))

A. Claims 1-10, 12, and 14-24 stand and fall together for purposes of this appeal.

B. Claims 11 and 13 stand and fall together for purposes of this appeal.

C. Claim 25 stands and falls alone for purposes of this appeal.

D. Claim 26 stands and falls alone for purposes of this appeal.

VIII. ARGUMENTS: REJECTIONS UNDER 35 USC §103 (37 CFR § 1.192(c)(8)(iv))

Claim Group A

The claims of Group A have been rejected as anticipated by Liu. Each of the claims is believed to be patentable over Liu at least because Liu does not disclose a cross-buffed device, system, or method as claimed wherein the ferroelectric liquid crystal material is free of chevron structures. Further Liu does not discuss the ferroelectric liquid crystal material being free of chevron structures without the need to otherwise apply an additional treatment to the optical device.

Generally, conventional ferroelectric liquid crystal (FLC) devices have undesirable chevron structures that are formed in the FLC material (see discussion in applicants' patent application at page 2, lines 18-33). Various attempts have been made to prevent the formation of chevron structures, such as applying an additional treatment in the form of an electrical signal to the FLC material after it is inserted into the device (see applicants' patent application at page 2, line 34 through page 3, line 3). When the chevrons are straightened out by such an additional treatment, they are said to have a structure called "quasi-bookshelf" (see attached relevant passages on pp 227-229 in Ferroelectric and Antiferroelectric Liquid Crystals, by Sven T. Lagerwall (1999) (the same passages were provided in the Response to Final Action filed May 27, 2003)).

Liu discusses chevrons and quasi-bookshelf structures in only two places in his patent (once in column 1 at lines 31-35, and again in column 4 at lines 35-37). In both places in Liu, the discussion is specifically limited to FLC cells that have either parallel or anti-parallel buffing; "crossed-buffed" cells are excluded. Thus, Liu is just reciting the prior-art problems with parallel-buffed devices that are also recited in applicants' patent application. Liu's teaching about his own invention, i.e. about cross-buffed FLC devices, is completely silent on the issue of chevrons. Applicants' invention is directed towards, and in its claims is limited to, FLC devices that are cross buffed. Therefore, Liu cannot anticipate applicants' invention.

The argument in the Final Office Action (as to why the Examiner believes that Liu discloses a chevron-free structure) is nonsensical. The statement on page 4, line 7 of the Final Office Action that "[a]ccordingly, Liu creates a structure free of chevron" does not follow from the previous two sentences in the Final Office Action. It is a classic non sequitur.

To anticipate a claim, a prior art reference must include each element in the claim. Chisum on Patents, 3.02 (2002). Further, the reference must describe the invention adequately to enable a person with ordinary skill in the art to comprehend and make the invention. Chisum on Patents,

3.04[1] (2002). The Liu reference is far from meeting this standard. There is no mention of a cross-buffed, chevron-free structure. There is also no mention of obtaining a chevron-free structure without the need for additional treatments. All of the claims in Group A are thus patentable over Liu.

Claim Group B

Claims 11 and 13 are patentable for all of the reasons stated above in conjunction with Claim Group A and because nowhere in Liu is there any teaching or suggestion of the optical retardance of the optical device remaining generally constant during continuous variation of the optical state of the light output. Since this key limitation is not disclosed in Liu, Liu cannot anticipate these claims. For this reason, in addition to the reasons discussed in conjunction with Claim Group A, the claims of Group B are patentable.

Claim Group C

Claim 25 is patentable not only because of the limitations discussed above in conjunction with Claim Group A, but also at least because of the surface stabilized limitation in Claim 25. The Final Office Action states on page 3 that Liu discloses "a non-surface-stabilized ferroelectric liquid crystal material to provide a chevron-free structure." (underlining added) It is not understood how this can be seen to anticipate the applicants' invention, which has a surface stabilized limitation. Liu's disclosure is directed to non-surface-stabilized structures, by his own admission (col. 2, lines 23-25, col. 8, line 24, and col. 9, line 25).

This key limitation in claim 25 is not disclosed in Liu and thus Liu cannot anticipate this claim. For this reason, in addition to the reasons discussed in conjunction with Claim Group A, the claim of Group C is patentable.

Claim Group D

Claim 26 is patentable not only because of the limitations discussed above in conjunction with Claim Group A, but also at least because of the "sufficiently small spacing to suppress formation of helixes" limitation in Claim 26. This limitation is not found in Liu in an embodiment that shows cross buffing.

This key limitation in Claim 26 is not disclosed in Liu and thus Liu cannot anticipate this claim. For this reason, in addition to the reasons discussed in conjunction with Claim Group A, the claim of Group D is patentable.

IX. CONCLUSION

Based upon the foregoing, Appellant respectfully requests the Board to reverse the Examiner's §102(e) rejections of all pending claims and to pass the above-identified patent application to issuance.

Respectfully submitted,

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Date: December 1, 2003

APPENDIX A

Clean Copy of the Claims

1. An optical device including a ferroelectric liquid crystal material, said optical device comprising:

a first and a second substrate;

a first alignment treatment applied to a surface of the first substrate, said first alignment treatment being intended to induce an orientation of at least a portion of said ferroelectric liquid crystal material along a first alignment direction and with a first pretilt angle α_1 with respect to a plane parallel to said first substrate;

a second alignment treatment applied to a surface of the second substrate, said second alignment treatment being intended to induce an orientation of at least another portion of said ferroelectric liquid crystal material along a second alignment direction and with a second pretilt angle α_2 with respect to a plane parallel to said second substrate; and

wherein the first substrate is located with respect to the second substrate in such a way that the surfaces of the first and second substrates onto which the first and second alignment treatments were applied, respectively, are spaced apart, generally parallel and facing each other and a projection of the first alignment direction onto the treated surface of the first substrate makes a non-zero angle Ω with respect to a projection of the second alignment direction onto the treated surface of the first substrate such that, said ferroelectric liquid crystal material being injected between the first and second substrates, the optical device is free of chevron structures without a need to otherwise apply an additional treatment to the optical device.

2. An optical device of Claim 1 wherein said ferroelectric liquid crystal material has a phase sequence of Isotropic – Nematic – Smectic A – Smectic C* – Crystalline states.

3. An optical device of Claim 1 wherein said ferroelectric liquid crystal material having a cone angle θ, said non-zero angle Ω has a predetermined value such that $\Omega \geq 2\theta$ and $\Omega \neq 180°$.

4. An optical device of Claim 1 wherein said first and second alignment treatments are specifically chosen so as to specifically induce pretilt angles of α_1 and α_2, respectively.

5. An optical device of Claim 4 wherein said first alignment treatment includes a coating of a selected alignment material, said coating being applied, cured and treated so as to specifically induce the pretilt angle of α_1.

6. An optical device of Claim 5 wherein said second alignment treatment includes a coating of another selected alignment material, said coating being applied, cured and treated so as to specifically induce the pretilt angle of α_2.

7. An optical device of Claim 4 wherein each of said pretilt angles is at most 10°.

8. An optical device of Claim 4 wherein said first and second alignment treatments are generally identical.

9. An optical device of Claim 1 wherein said first and second alignment treatments provide strong molecular anchoring of at least portions of the ferroelectric liquid crystal material located immediately adjacent to the treated surfaces of the first and second substrates.

10. An optical device of Claim 1 further comprising:

a light input directed at said optical device in such a way that the optical device in turn produces a light output of a particular optical state; and

means for electrically addressing said optical device in such a way that the particular optical state of the light output is continuously variable between a minimum optical state and a maximum optical state.

11. An optical device of Claim 1 wherein an optical retardance of the optical device remains generally constant during said continuous variation of the optical state of the light output.

12. An optical device of Claim 1 wherein said first substrate includes a reflective surface.

13. An optical system comprising:

an optical device including

a ferroelectric liquid crystal material,

a first and a second substrate,

a first alignment treatment applied to a surface of the first substrate, said first alignment treatment being intended to induce an orientation of at least a portion of said ferroelectric liquid crystal material along a first alignment direction and with a first pretilt angle α_1 with respect to a plane parallel to said first substrate,

a second alignment treatment applied to a surface of the second substrate, said second alignment treatment being intended to induce an orientation of at least another portion of said ferroelectric liquid crystal material along a second alignment direction and with a second pretilt angle α_2 with respect to a plane parallel to said second substrate, and

wherein the first substrate is located with respect to the second substrate in such a way that the surfaces of the first and second substrates onto which the first and second alignment treatments were applied, respectively, are spaced apart, generally parallel and facing each other and a projection of the first alignment direction onto the treated surface of the first substrate makes a non-zero angle Ω with respect to a projection of the second alignment direction onto the treated surface of the first substrate such that, said ferroelectric liquid crystal material being injected between the first and second substrates, the optical device is free of chevron structures without a need to otherwise apply an additional treatment to the optical device;

a light input directed at said optical device in such a way that the optical device in turn produces a light output of a particular optical state; and

means for electrically addressing said optical device in such a way that the particular optical state of the light output is continuously variable between a minimum optical state and a maximum optical state wherein an optical retardance of the optical device remains generally constant during said continuous variation of the optical state of the light output.

14. In an optical device including a ferroelectric liquid crystal material, a method for preventing formation of chevron structures in the optical device, said method comprising the steps of:

providing a first and a second substrate;

applying a first alignment treatment to a surface of the first substrate, said first alignment treatment being intended to induce an orientation of at least a portion of said ferroelectric liquid crystal material along a first alignment direction and with a first pretilt angle α_1 with respect to a plane parallel to said first substrate;

applying a second alignment treatment to a surface of the second substrate, said second alignment treatment being intended to induce an orientation of at least another portion of said ferroelectric liquid crystal material along a second alignment direction and with a second pretilt angle α_2 with respect to a plane parallel to said second substrate;

locating the first substrate with respect to the second substrate in such a way that the surfaces of the first and second substrates onto which the first and second alignment treatments were applied, respectively, are spaced apart, generally parallel and facing each other and a projection of the first alignment direction onto the treated surface of the first substrate makes a non-zero angle Ω with respect to a projection of the second alignment direction onto the treated surface of the first substrate; and

injecting the ferroelectric liquid crystal material between the first and second substrates such that the optical device is free of chevron structures without a need to otherwise apply an additional treatment to the optical device.

15. The method of Claim 14 further comprising the step of selecting a ferroelectric liquid crystal material having a phase sequence of Isotropic – Nematic – Smectic A –Smectic C* – Crystalline states.

16. The method of Claim 14 wherein, said ferroelectric liquid crystal material having a cone angle θ, said step of securing the first substrate with respect to the second substrate includes the step of specifying the value of angle Ω to have a value such that $\Omega \geq 2\theta$ and $\Omega \neq 180°$.

17. The method of Claim 14 further comprising the step of choosing said first and second alignment treatments so as to specifically induce pretilt angles of α_1 and α_2, respectively.

18. The method of Claim 17 wherein said step of applying the first alignment treatment to a surface of the first substrate further includes the steps of:

coating the surface with a selected alignment material;

curing said coated surface using a heating and cooling sequence; and

rubbing said cured, coated surface using a buffing material in such a way that at least a portion of said ferroelectric liquid crystal material tends to become orientated of along the first alignment direction with the first pretilt angle α_1 with respect to the plane parallel to said first substrate.

19. The method of Claim 18 said step of applying the second alignment treatment to a surface of the second substrate further includes the steps of:

coating the surface with another selected alignment material;

curing said coated surface using another heating and cooling sequence; and

rubbing said cured, coated surface using a buffing material in such a way that at least another portion of said ferroelectric liquid crystal material tends to become orientated of along the second alignment direction with the second pretilt angle α_2 with respect to the plane parallel to said second substrate.

20. The method of Claim 17 wherein sad step of applying the first alignment treatment to a surface of the first substrate and said step of applying the second alignment treatment to a surface of the second substrate are generally identical.

21. The method of Claim 17 wherein said choosing step further includes the step of taking into consideration molecular anchoring properties of said first and second alignment treatments so as to choose first and second alignment treatments to specifically induce pretilt angles of α_1 and α_2, respectively, while providing strong molecular anchoring of at least portions of the ferroelectric liquid crystal material located immediately adjacent to the treated surfaces of the first and second substrates.

22. The method of Claim 14 further comprising the steps of:

providing a light input to said optical device in such a way that the optical device in turn produces a light output of a particular optical state; and

electrically addressing said optical device in such a way that the particular optical state of the light output is continuously variable between a minimum optical state and a maximum optical state.

23. An optical device of Claim 9, wherein the first and second pretilt angles are non-zero.

24. An optical device of Claim 21, wherein the first and second pretilt angles are non-zero.

25. An optical device including a ferroelectric liquid crystal material, said optical device comprising:

a first and a second substrate;

a first alignment treatment applied to a surface of the first substrate, said first alignment treatment being intended to induce an orientation of at least a portion of said ferroelectric liquid crystal material along a first alignment direction and with a first pretilt angle α_1 with respect to a plane parallel to said first substrate;

a second alignment treatment applied to a surface of the second substrate, said second alignment treatment being intended to induce an orientation of at least another portion of said ferroelectric liquid crystal material along a second alignment direction and with a second pretilt angle α_2 with respect to a plane parallel to said second substrate; and

wherein the first substrate is located with respect to the second substrate in such a way that the surfaces of the first and second substrates onto which the first and second alignment treatments were applied, respectively, are spaced apart, generally parallel and facing each other and a projection of the first alignment direction onto the treated surface of the first substrate makes a non-zero angle Ω with respect to a projection of the second alignment direction onto the treated surface of the first substrate such that, said ferroelectric liquid crystal material being injected between the first and second substrates, the optical device is free of chevron structures without a need to otherwise apply an additional treatment to the optical device; and

wherein the ferroelectric liquid crystal material in the optical device is surface stabilized.

26. An optical device including a ferroelectric liquid crystal material, said optical device comprising:

a first and a second substrate;

a first alignment treatment applied to a surface of the first substrate, said first alignment treatment being intended to induce an orientation of at least a portion of said ferroelectric liquid crystal material along a first alignment direction and with a first pretilt angle α_1 with respect to a plane parallel to said first substrate;

a second alignment treatment applied to a surface of the second substrate, said second alignment treatment being intended to induce an orientation of at least another portion of said ferroelectric liquid crystal material along a second alignment direction and with a second pretilt angle α_2 with respect to a plane parallel to said second substrate; and

wherein the first substrate is located with respect to the second substrate in such a way that the surfaces of the first and second substrates onto which the first and second alignment treatments were applied, respectively, are spaced apart, generally parallel and facing each other and a projection of the first alignment direction onto the treated surface of the first substrate makes a non-zero angle Ω with respect to a projection of the second alignment direction onto the treated surface of the first substrate such that, said ferroelectric liquid crystal material being injected between the first and second substrates, the optical device is free of chevron structures without a need to otherwise apply an additional treatment to the optical device; and

wherein the first and second substrates are spaced apart by a distance sufficiently small to suppress formation of helixes typically formed in bulk of the ferroelectric liquid crystal material.

APPENDIX B

Copy of U.S. Patent No. 6,141,076.

US006141076A

United States Patent [19]
Liu et al.

[11] Patent Number: 6,141,076
[45] Date of Patent: Oct. 31, 2000

[54] **SPATIAL LIGHT MODULATORS CONSTRUCTED FROM FERROELECTRIC LIQUID CRYSTAL DEVICES WITH TWISTED STRUCTURE**

[75] Inventors: **Jian-Yu Liu; Kuang-Yi Wu; Seng-Ieong Wong**, all of Boulder, Colo.

[73] Assignee: **Chorum Technologies, Inc.**, Richardson, Tex.

[21] Appl. No.: **08/980,447**

[22] Filed: **Nov. 28, 1997**

[51] **Int. Cl.**^{7} **G02F 1/141**
[52] **U.S. Cl.** **349/134**; 349/171
[58] **Field of Search** 349/133, 134, 349/171, 172, 173

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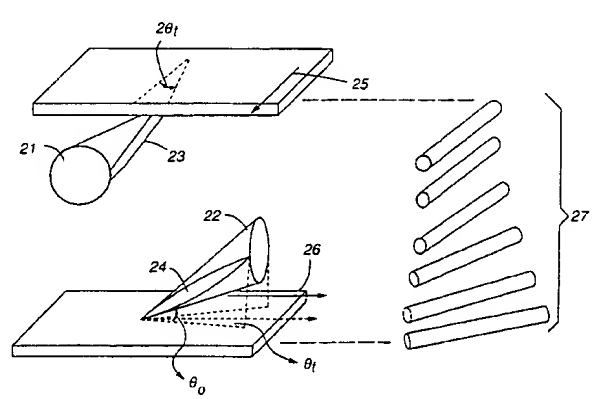
Primary Examiner—Kenneth Parker
Attorney, Agent, or Firm—Sheridan Ross P.C.

[57] **ABSTRACT**

A hybrid analog/binary electro-optic modulator using a twisted ferroelectric liquid crystal structure is provided. Ferroelectric liquid crystals with a tilt angle of between about 20° and about 25°, preferably about 22.5° are used. Rubbing directions for the two cell walls (relative to one another) can be varied from about 45° to about 90°. In one embodiment, a weak buffing force is used resulting in a relatively weak anchoring energy at the surface, aligning the liquid crystal molecules without locking the molecules into the buffing directions and a high pre-tilt structure for the molecules close to the surface boundaries. In one embodiment, strong buffing is used with buffing directions offset about 45°. Use of this invention provides relatively fast response time, low required driving voltage, high contrast, and/or the ability to achieve both analog and binary operations.

16 Claims, 12 Drawing Sheets



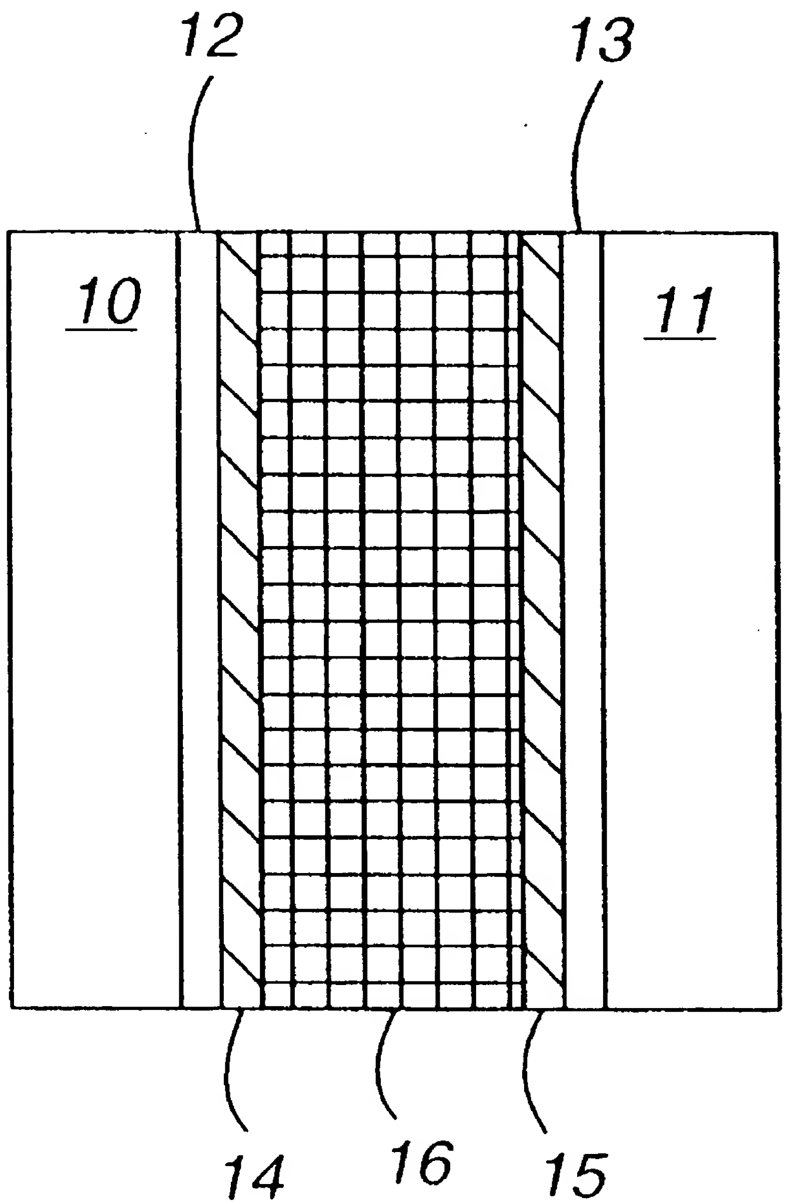


Fig. 1

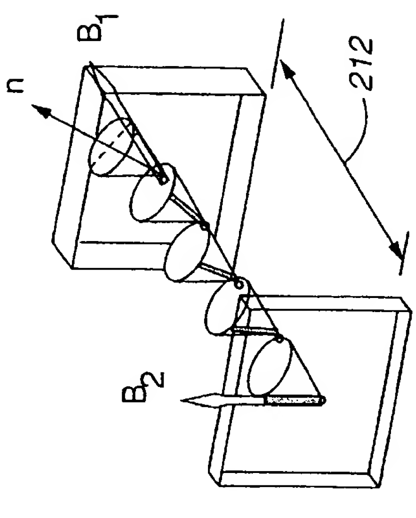


Fig. 2A

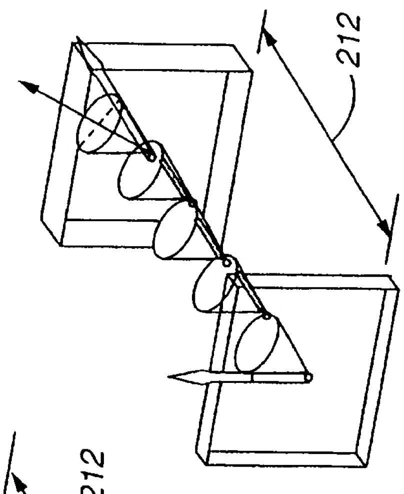


Fig. 2B

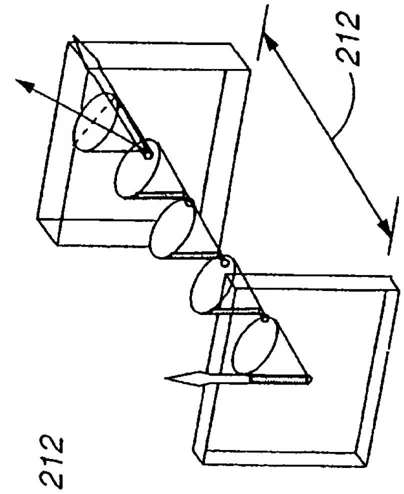


Fig. 2C

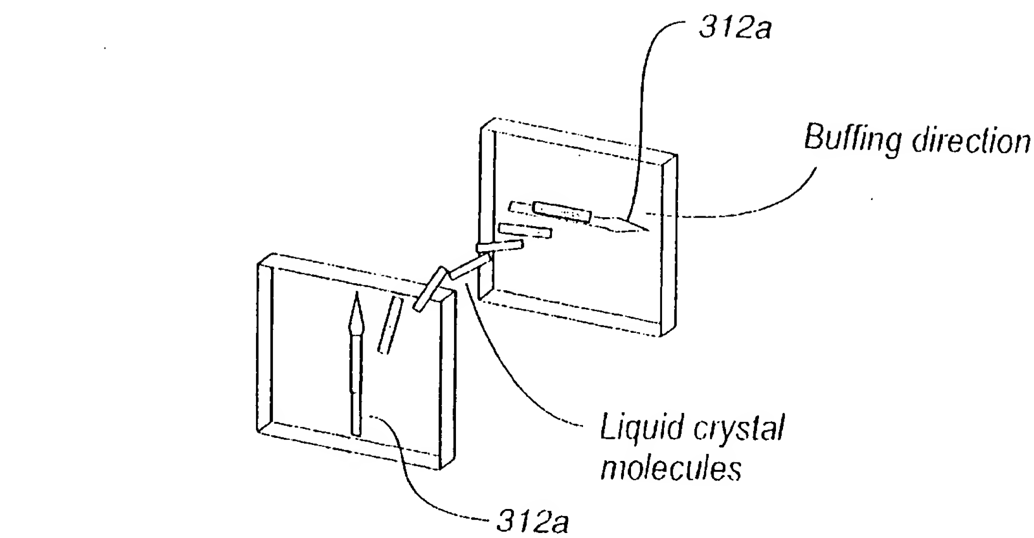

312a
Buffing direction
Liquid crystal
molecules
312a

Fig. 3 A

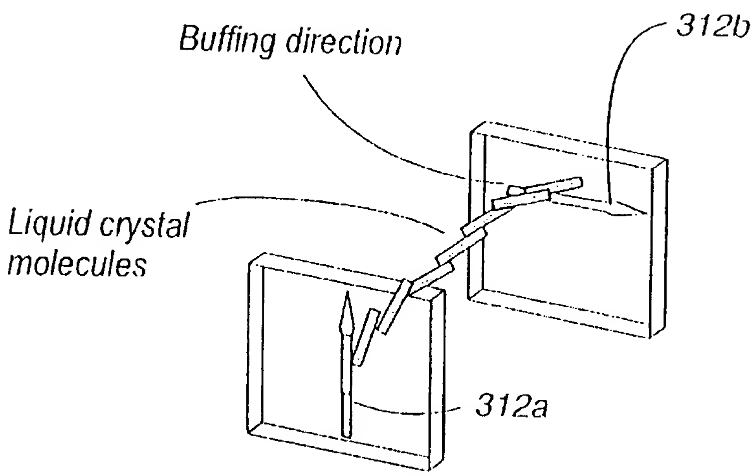

Buffing direction
312b
Liquid crystal
molecules
312a

Fig. 3 B

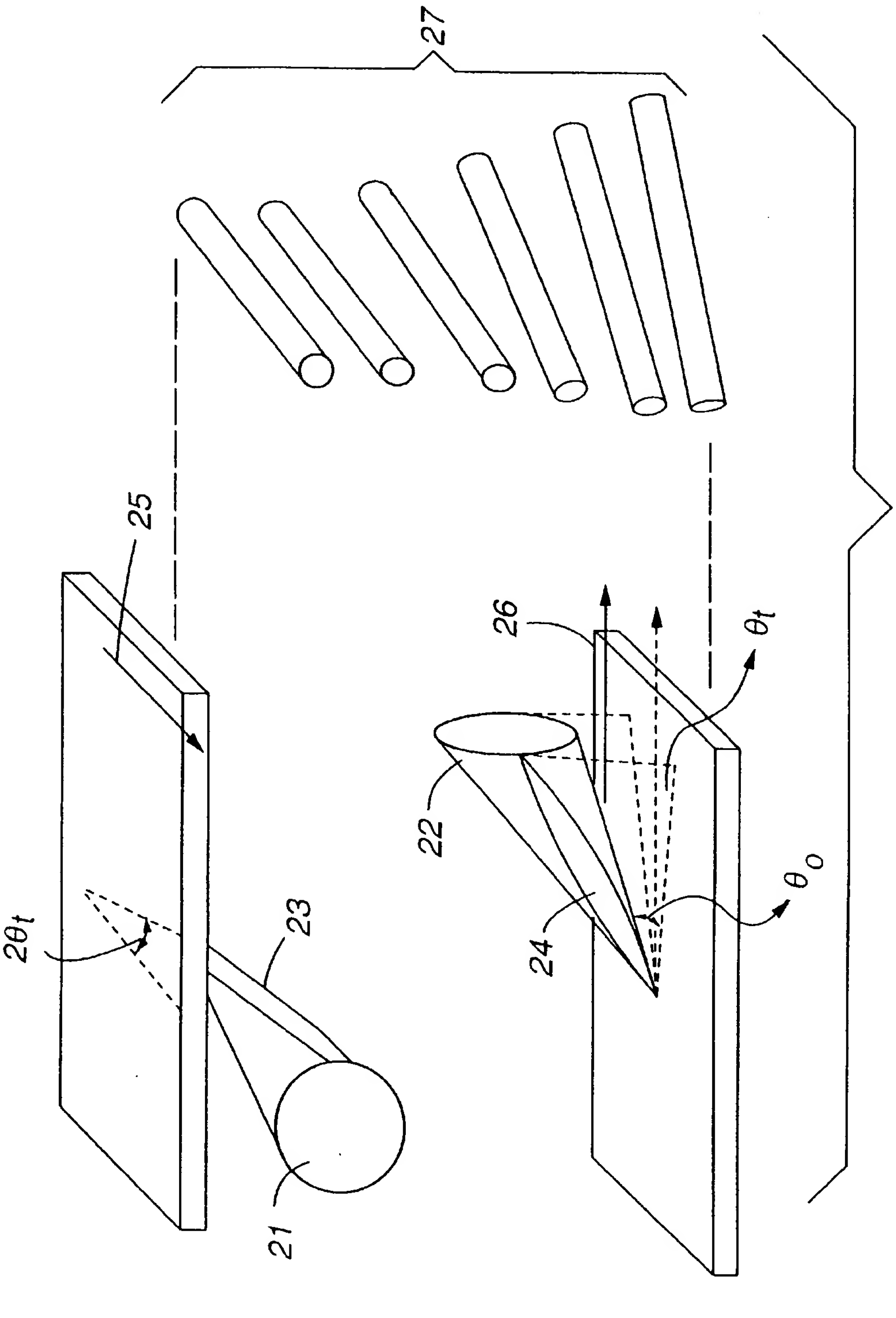


Fig. 4

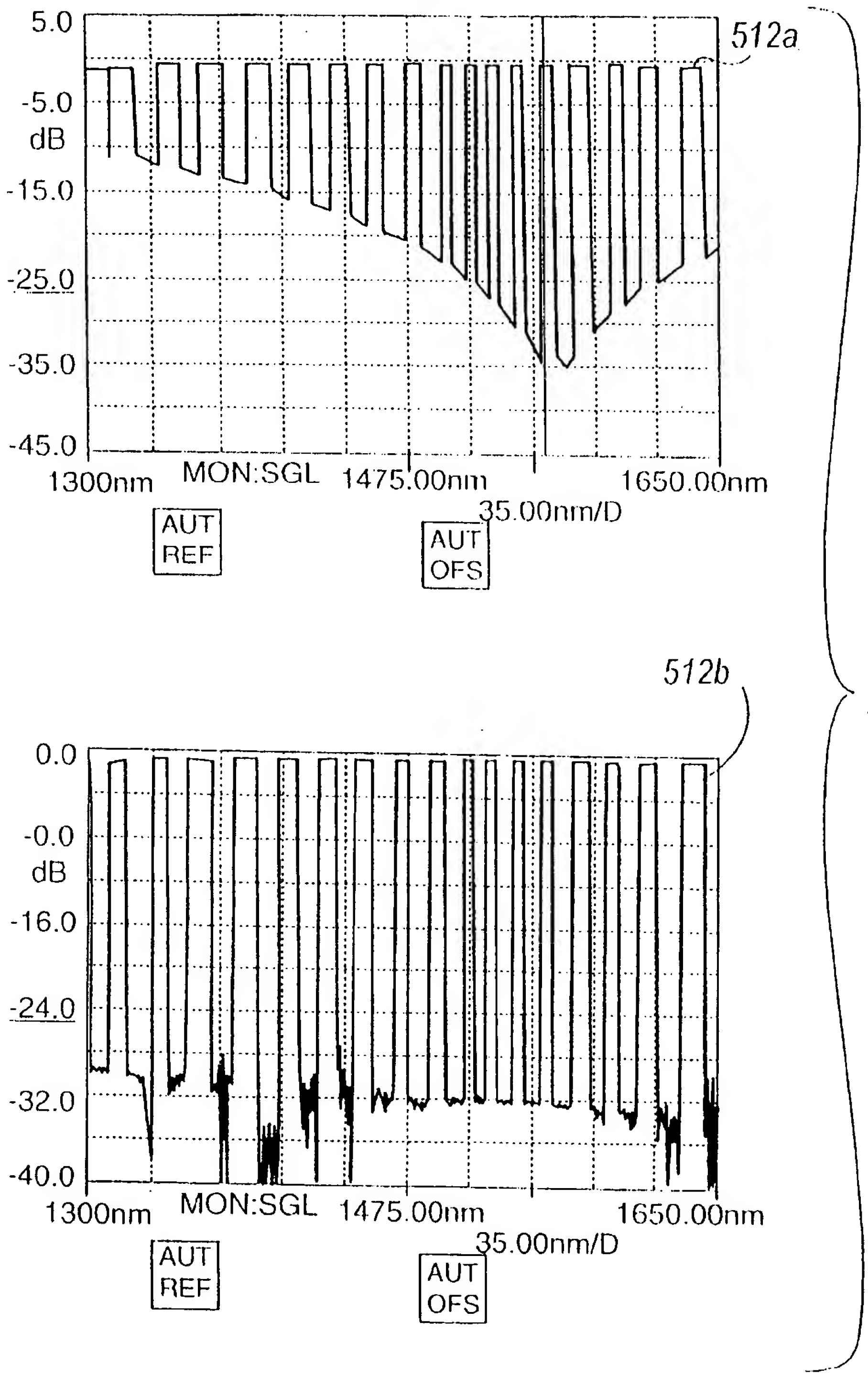

512a
5.0
-5.0
dB
-15.0
-25.0
-35.0
-45.0
1300nm
MON:SGL
1475.00nm
1650.00nm
35.00nm/D
AUT
REF
AUT
OFS
512b
0.0
-0.0
dB
-16.0
-24.0
-32.0
-40.0
1300nm
MON:SGL
1475.00nm
1650.00nm
35.00nm/D
AUT
REF
AUT
OFS

Fig. 5

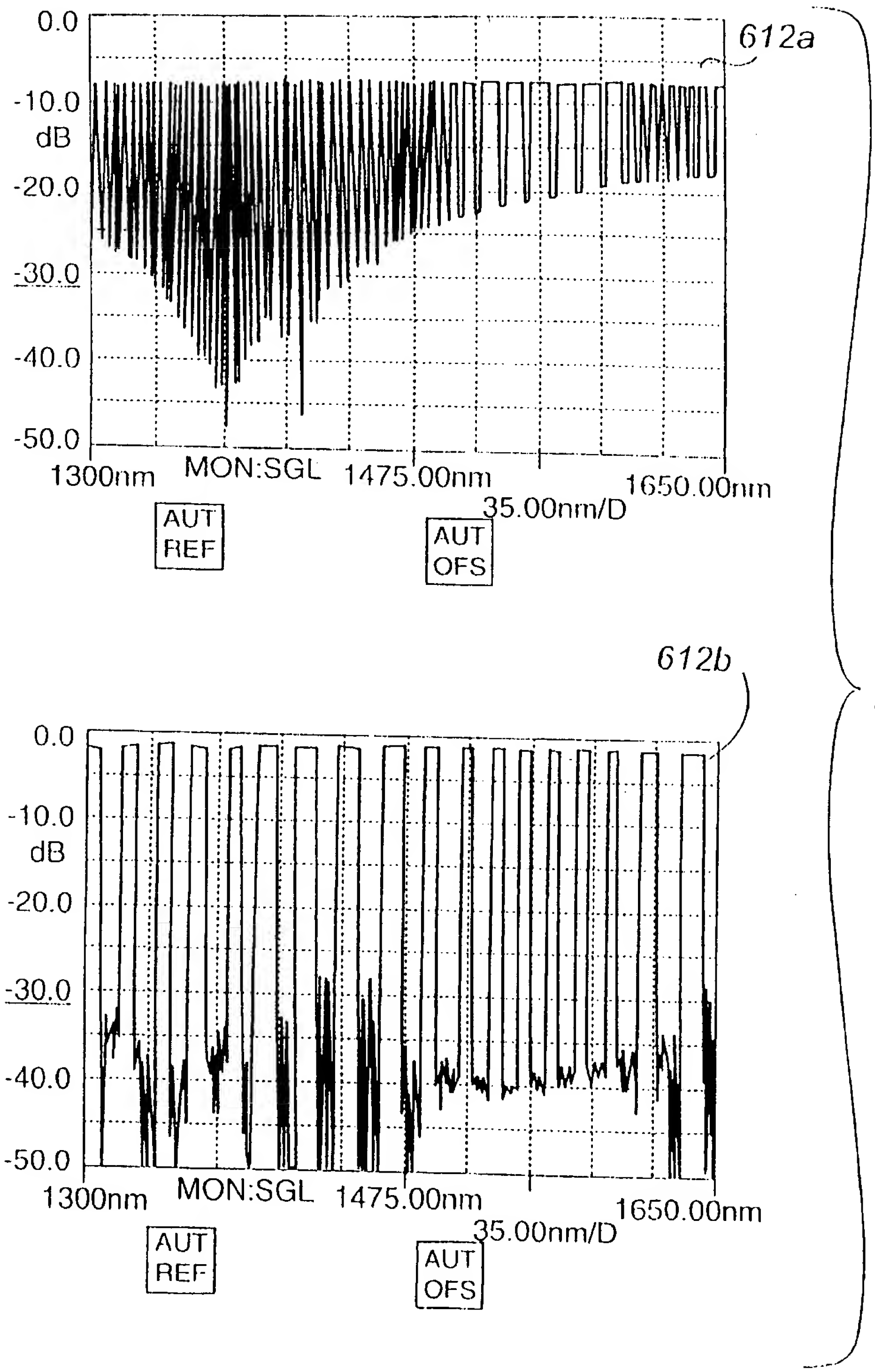

612a
0.0
-10.0
dB
-20.0
-30.0
-40.0
-50.0
1300nm
MON:SGL
1475.00nm
1650.00nm
35.00nm/D
AUT
REF
AUT
OFS
612b
0.0
-10.0
dB
-20.0
-30.0
-40.0
-50.0
1300nm
MON:SGL
1475.00nm
1650.00nm
35.00nm/D
AUT
REF
AUT
OFS

Fig. 6

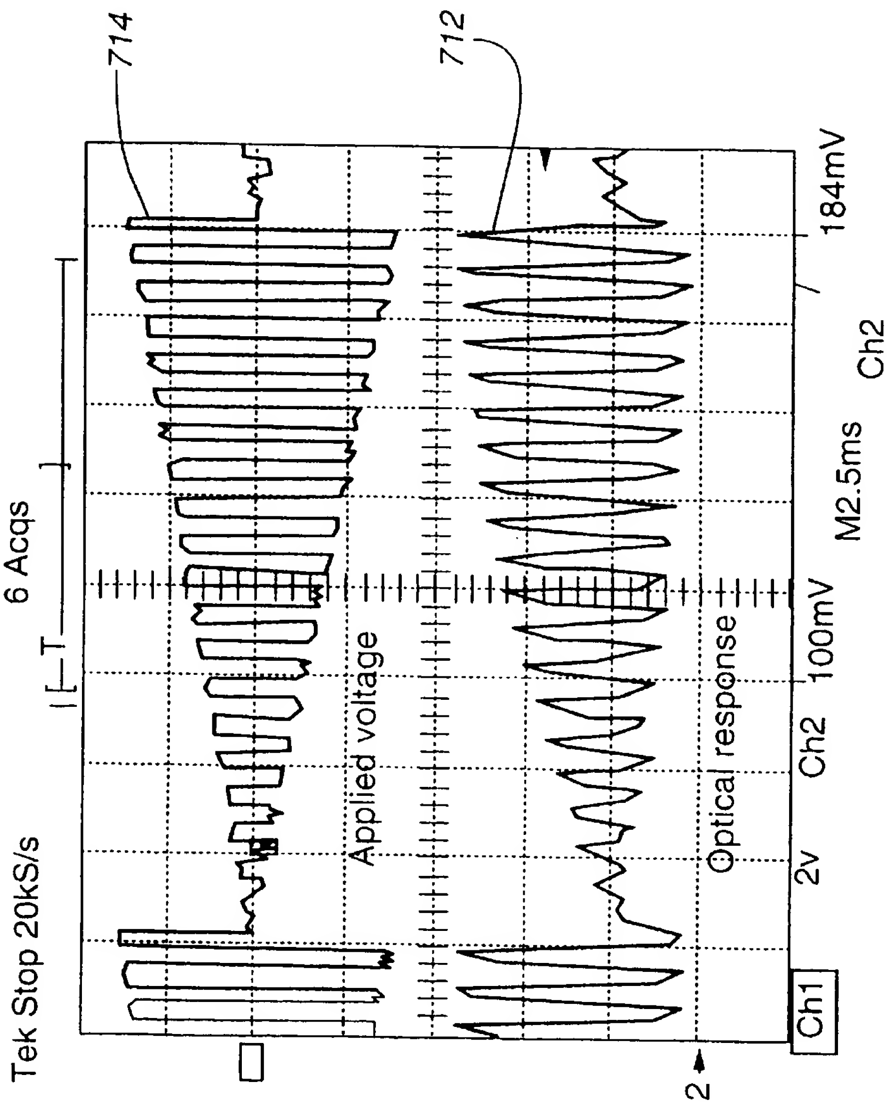

Tek Stop 20kS/s
6 Acqs
T
714
712
Applied voltage
Optical response
Ch1
2v
Ch2
100mV
M2.5ms
Ch2
184mV
2

Fig. 7

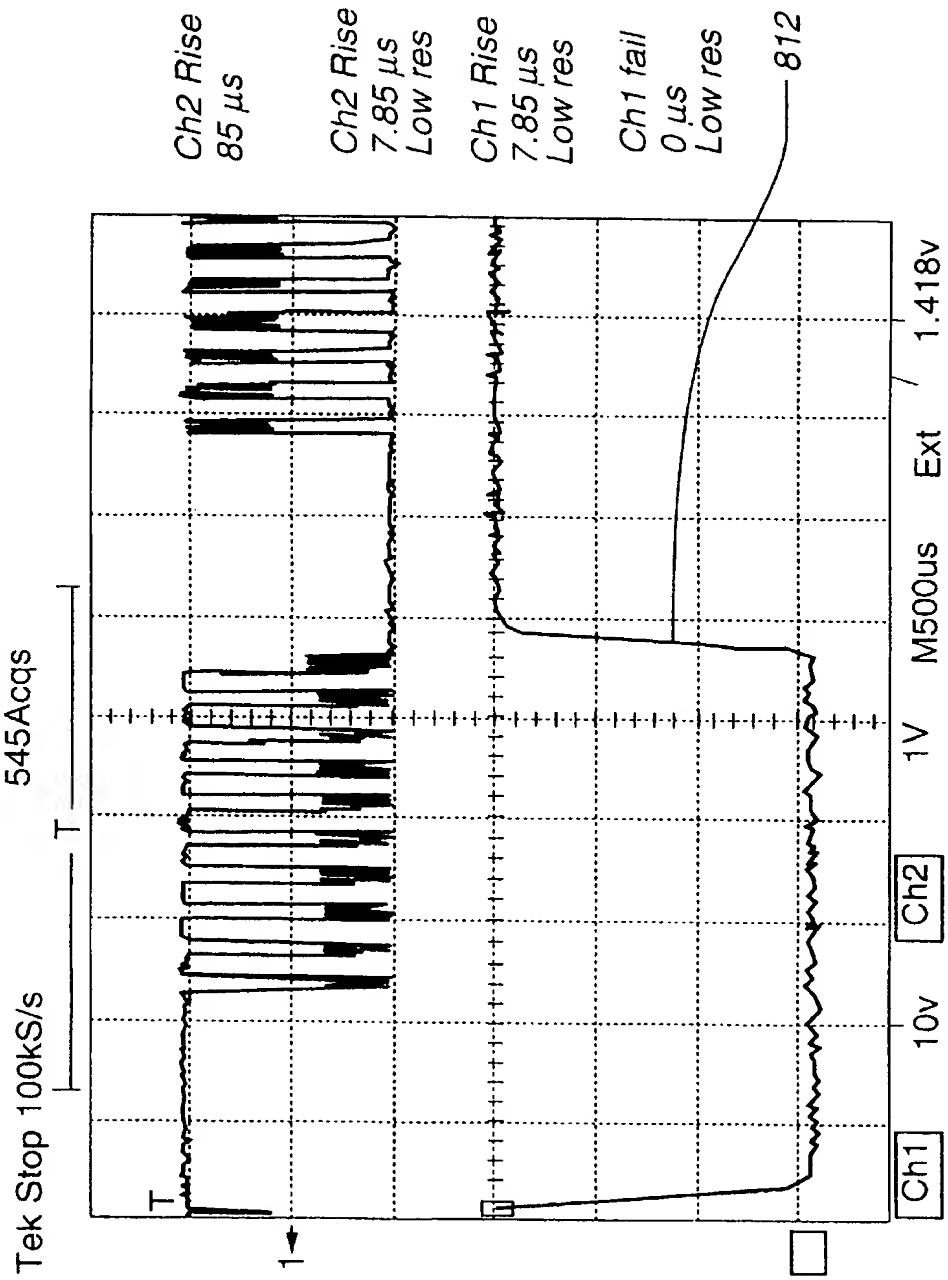

Tek Stop 100kS/s
545Acqs
Ch2 Rise
85 µs
Ch2 Rise
7.85 µs
Low res
Ch1 Rise
7.85 µs
Low res
Ch1 fail
0 µs
Low res
812
Ch1
10v
Ch2
1V
M500us
Ext
1.418v

Fig. 8

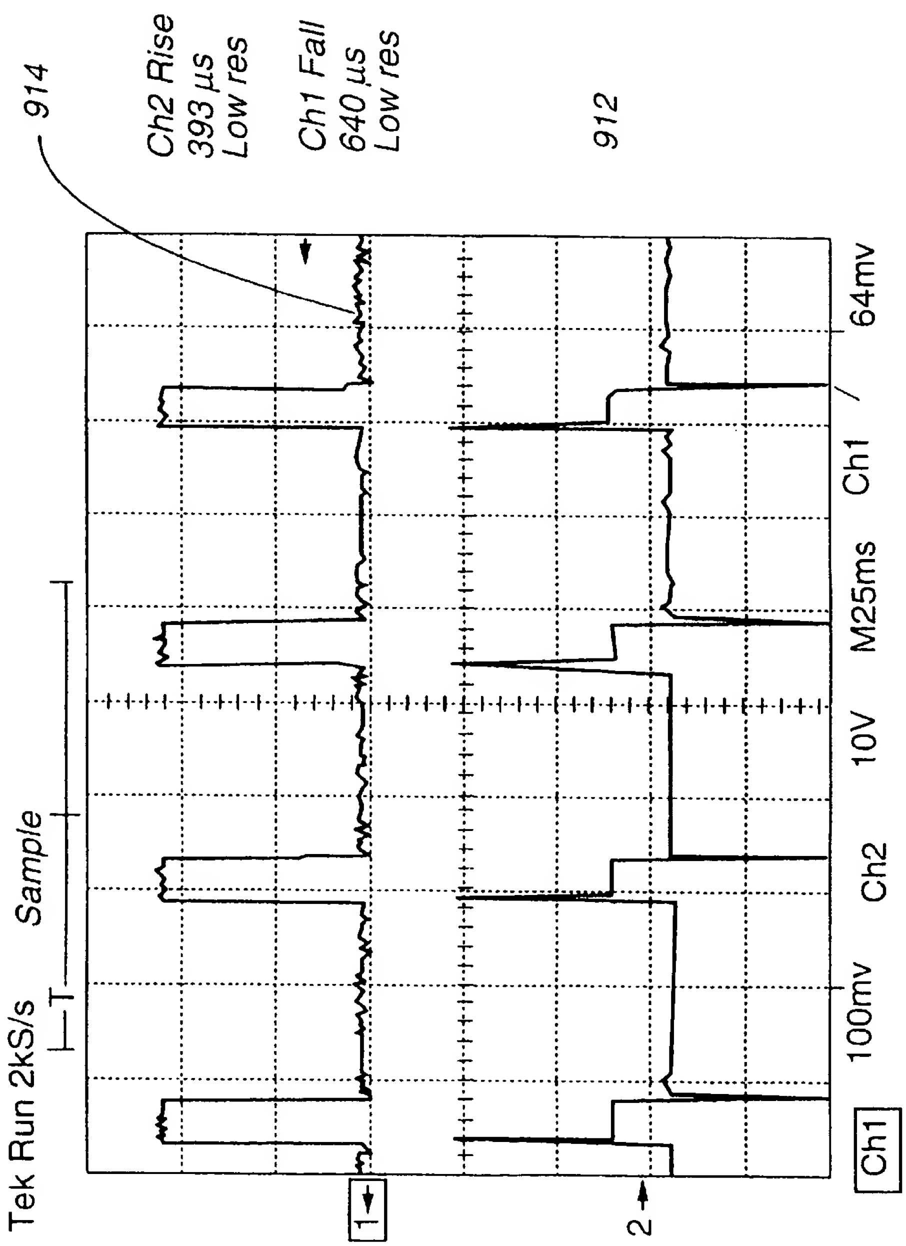

Tek Run 2kS/s
T
Sample
914
Ch2 Rise
393 µs
Low res
Ch1 Fall
640 µs
Low res
912
1
2
Ch1 100mv Ch2 10V M25ms Ch1 / 64mv

Fig. 9

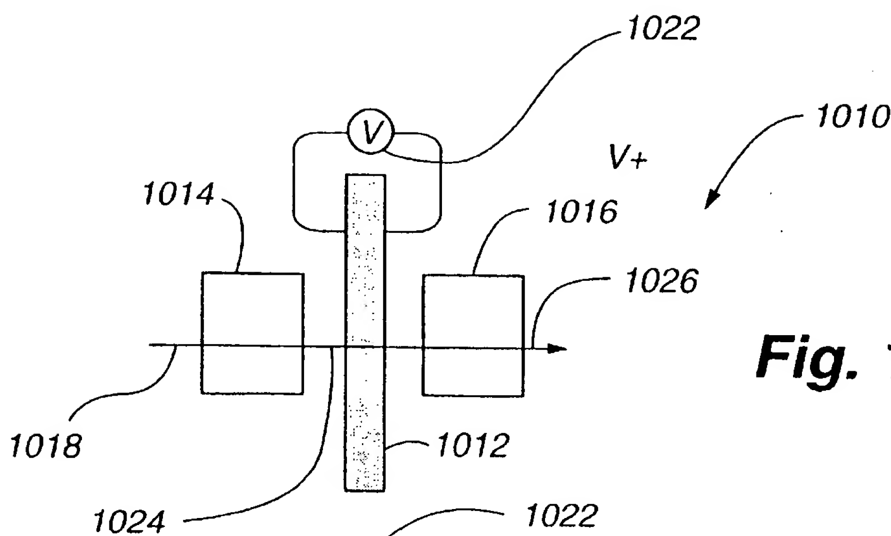


Fig. 10A

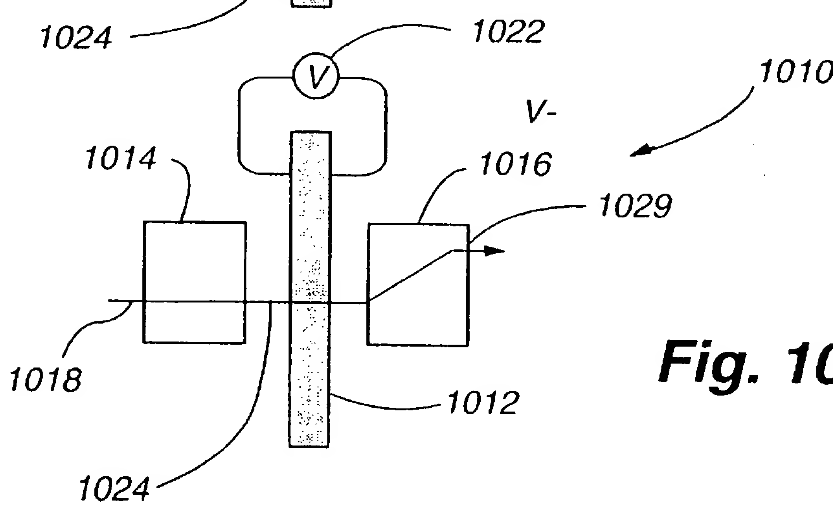
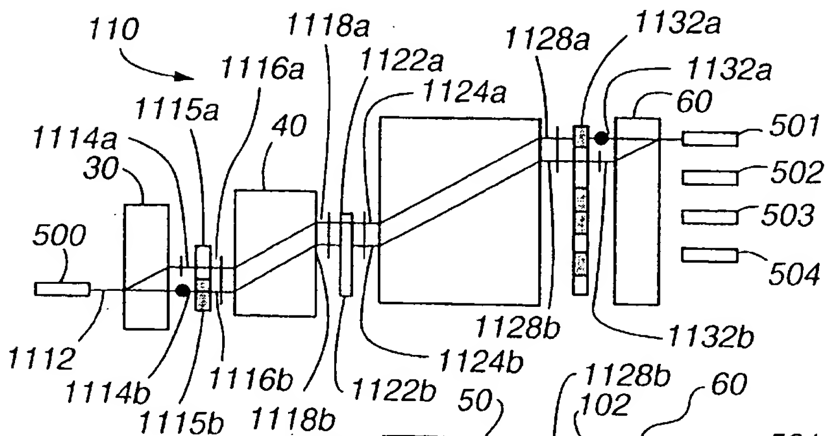


Fig. 10B

Fig. 11A



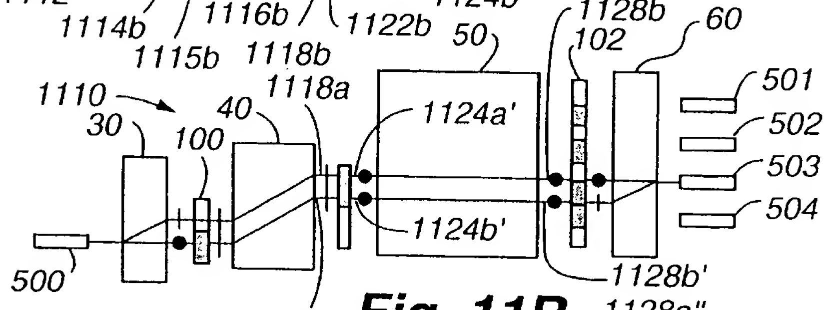


Fig. 11B

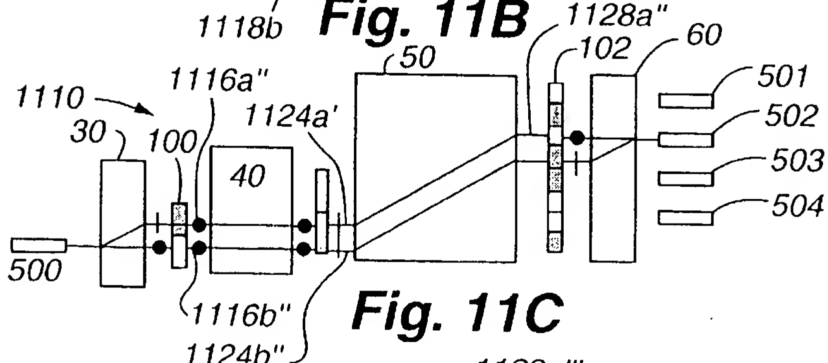
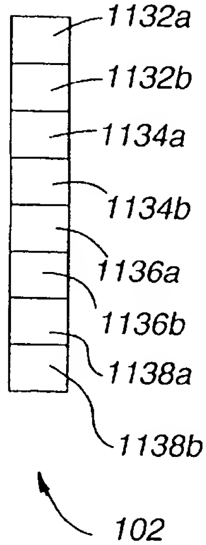


Fig. 11C



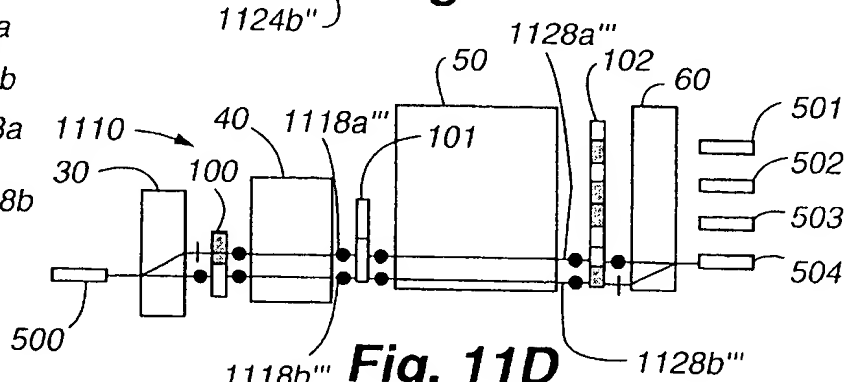


Fig. 11D

Fig. 11E

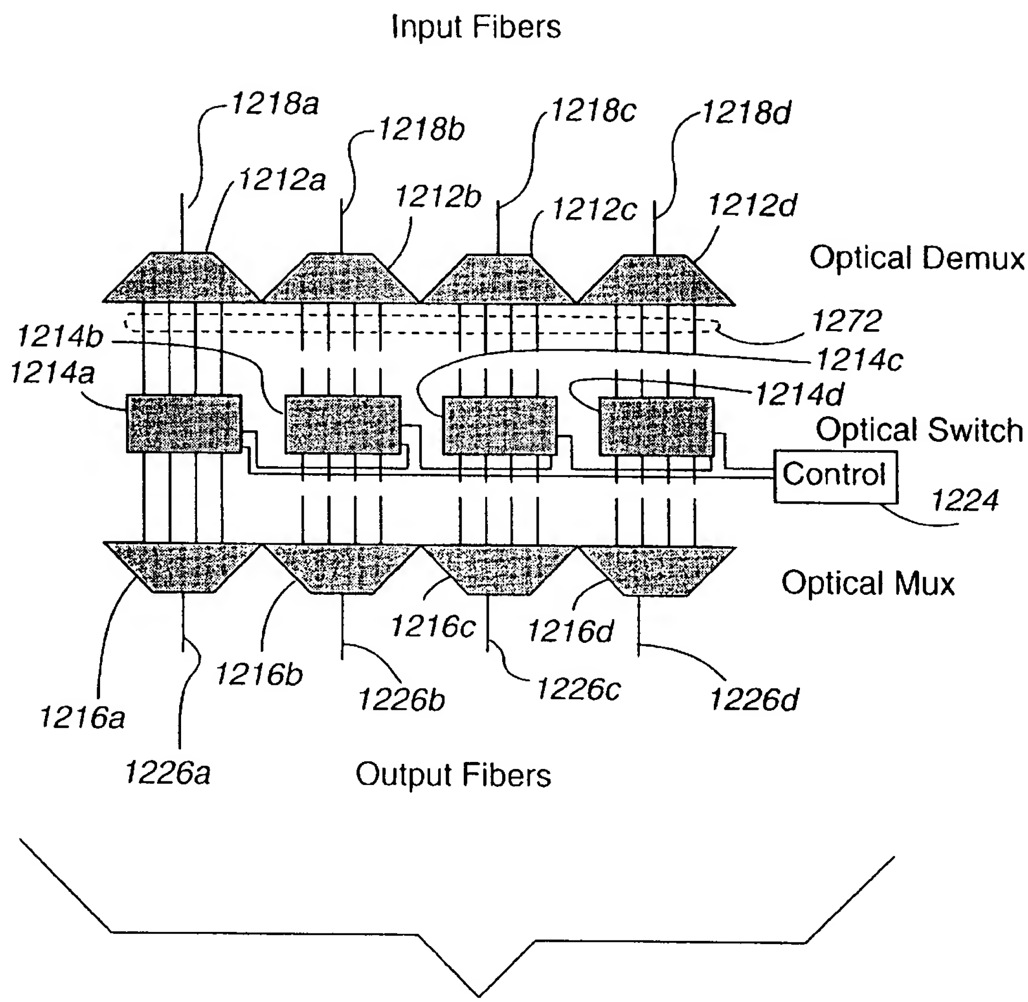

Input Fibers
1218a
1218b
1218c
1218d
1212a
1212b
1212c
1212d
Optical Demux
1272
1214b
1214a
1214c
1214d
Optical Switch
Control
1224
Optical Mux
1216c
1216d
1216b
1226b
1226c
1226d
1216a
1226a
Output Fibers

Fig. 12

SPATIAL LIGHT MODULATORS CONSTRUCTED FROM FERROELECTRIC LIQUID CRYSTAL DEVICES WITH TWISTED STRUCTURE

This invention relates, in general, to ferroelectric liquid crystal devices. In particular, the invention relates to spatial light modulators made from ferroelectric liquid crystal materials.

BACKGROUND INFORMATION

Ferroelectric liquid crystal (FLC) substances have been widely used as electro-optic modulators in applications such as flat panel displays, spatial light modulators, and specialized optical image processors, where switching times on the order of microseconds are needed. They are generally fabricated into surface-stabilization structures, so-called SSFLC (surface stabilized ferroelectric liquid crystal), for binary operation. (N. A. Clark et al., "Submicrosecond bistable electro-optic switching in liquid crystals," Appl. Phys. Lett. 36(11), p.# 899, 1980.).

A typical SSFLC modulator is made by the following process. Transparent electrode (indium-tin-oxide) coated glass substrates are generally used for the cell walls. They are spin-coated with alignment material, for example nylon or polyimide, and then rubbed with silk to form an alignment layer. The two substrates are brought together with the rubbing directions parallel or anti-parallel to each other. The cell thickness is kept much smaller than the pitch length of the liquid crystal material such that the liquid crystal helix is suppressed by the cell walls (glass substrates). The assembly creates a "chevron" structure when parallel rubbing is applied or a "quasi-bookshelf" structure when anti-parallel rubbing is applied to the substrates.

In these structures, liquid crystal molecules are switched between two states when positive and negative electrical fields are applied to them. This is due to the interaction between the applied electric field and the spontaneous polarization of the molecules. By selecting a ferroelectric liquid crystal material that has an angle of 45° between the two states, the modulator becomes a switchable waveplate. By further designing the thickness of the liquid crystal cell such that $\Delta n\ d=\lambda/2$, the modulator acts as a switchable half-wave plate that can rotate the input linear polarization by 0° or 90°. The parameters Δn and d are the optical birefringence and the thickness of the liquid crystal material, respectively, and λ is the operating wavelength. An input optical signal with its linear polarization aligned to one of the liquid crystal states experiences no polarization modulation. (The optical signal experiences only a phase delay.) When the molecules are switched to the opposite state at 45°, the polarization of the optical signal is rotated 90°. A simple on/off switch can be constructed based on this ferroelectric liquid crystal modulator when two polarizers are added to the input and output of the device.

In the SSFLC mode, because the helix of the liquid crystal molecules is suppressed by the surface anchoring energy provided by the alignment layer, no analog modulation is allowed. The device operates in a binary switching mode.

Another type of ferroelectric liquid crystal modulator based on a twisted structure was disclosed by Patel, in U.S. Pat. No. 5,172,257. In this type of twisted ferroelectric liquid crystal modulator, the glass substrates are strongly rubbed or "buffed" at an angle of 90° relatively to each other. Ferroelectric liquid crystals with a large tilt angle, about 90°, are used to fill the cell gap. Because of the strong buffing, liquid crystal molecules adjacent to both cell walls align to the buffing directions. The smectic layer of the liquid crystal is formed with its layer normal laid at 45° relative to the two rubbing directions. Without the electrical field, the twisted structure waveguides the polarization of the input light to rotate the polarization by 90°. With application of electrical fields, the waveguiding effect is distorted and the polarization is rotated partially. With the modulator sandwiched in between two crossed or parallel polarizers, analog intensity modulation can be obtained.

In this analog modulation case, the device is modulated between 0 and V or 0 and −V voltage states. When application voltage $V>V_{sat}$ is used (where V_{sat} is the saturation voltage) the molecules are switched at 0° and 90° positions (because a 45° tilt angle material is used). With parallel or vertical polarization input to the modulator, only phase modulation (from $n_e d/\lambda$ to $n_o d/\lambda$, or vice versa, (where n_o is the ordinary refractive index of the liquid crystal and n_e is the so-called extra-ordinary refractive index) is obtained and no intensity modulation results.

SUMMARY OF THE INVENTION

The present invention provides a hybrid analog/binary electro-optic modulator using a twisted non-surface-stabilized ferroelectric liquid crystal structure. Ferroelectric liquid crystals with a tilt angle of between about 20° and about 25°, preferably about 22.5° are used. Rubbing directions for the two cell walls (relative to one another) can be varied from about 45° to about 90°. Use of this invention provides relatively fast response time, low required driving voltage and/or the ability to achieve both analog and binary operations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates the cross-section of a ferroelectric liquid crystal modulator with a twisted structure;

FIGS. **2A**, **2B** and **2C** are schematic perspective views that illustrate the alignment of a molecular director within the twist structure for different voltages;

FIGS. **3A** and **3B** show the two buffing schemes to achieve twists in ferroelectric liquid crystal structures;

FIG. **4** is a partially exploded schematic perspective view illustrating a high contrast binary twisted ferroelectric liquid crystal modulator according to an embodiment of this invention;

FIG. **5** is a graph showing contrast, in dB, as a function of wavelength in an example using an analog modulation device, according to an embodiment of this invention for a twist angle of 45°;

FIG. **6** is a graph showing contrast, in dB, as a function of wavelength in an example using an analog modulation device, according to an embodiment of this invention for a twist angle of 90°;

FIG. **7** is a graph comparing applied voltage and optical response for analog modulation using a device according to an embodiment of the present invention;

FIG. **8** is a graph illustrating switching time of a twisted ferroelectric liquid crystal modulator according to an embodiment of the present invention;

FIG. **9** is a graph illustrating modulator switching in response to an applied pulse in a device according to an embodiment of the present invention;

FIGS. **10A** and **10B** are schematic diagrams of a modulation device, according to an embodiment of the present

invention, providing light output along first and second paths, respectively;

FIGS. 11A–D are schematic diagrams of a one by four switch, according to an embodiment of the present invention, providing light output along first, third, second and fourth paths respectively;

FIG. 11E is an enlarged schematic depiction of the third rotator of FIG. 11A; and

FIG. 12 is a schematic diagram of an optical crossconnect, according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Electro-optic modulators made of twisted nematic (TN) are well known devices in the field of spatial light modulators. Most current flat panel displays use TN as the modulation base. Application of electro-optic modulators to telecommunications systems presents different sets of performance goals, including switching times, voltage requirements and digital/analog operations, to which the present invention is believed particularly suited. The present invention is believed to depart from previous techniques at least in terms of the basic physical insight taught by this invention, down to the molecular level, and optical properties.

FIG. 1 illustrates the basic elements and structure used in an embodiment of this invention to obtain a twisted ferroelectric liquid crystal modulator. Transparent electrodes, such as indium-tin-oxide electrodes **12** and **13** are deposited onto substrates such as glass substrates **10** and **11**. Alignment layers **14** and **15**, formed from materials such as polyimide, are applied, e.g. by spin-coating, onto the substrates, followed by a standard curing procedure, when appropriate for these alignment layers.

In one embodiment, the alignment layers are treated to create a preferably weak anchoring force, such as by lightly rubbing along a predetermined direction. The anchoring force is used to align the liquid crystal molecules adjacent to the alignment layers. The two substrates are brought together to define a space therebetween, preferably with the rubbing directions being different from one another to define a twist angle therebetween. In some embodiments of the present invention, twist angles of about 90° and 44° are provided between the two glass substrates. Ferroelectric liquid crystal material, such as that sold under the trade designation 1026, available from Chisso America, Inc., is used to fill into the cell gap. The material's cone angle is 22° at room temperature.

Ferroelectric liquid crystal has a helical structure. As shown in FIGS. 2A–2C, molecules rotate (B_1, B_2) around the cone (with an angle of θ_r) and form a helix between smectic layers. In the surface stabilized mode, the cell thickness **212** is designed to be thin and the surface anchoring energy is strong. This combined force suppresses the helix and results in two eigen positions for the liquid crystal molecules. Therefore, with electric fields applied to the cell (FIGS. 2B and 2C), the molecules switch between the two far ends of the cone that modulate the light beam in a binary fashion. In the conventional parallel or antiparallel buffing case, the smectic layer normal is formed parallel to the buffing direction. The liquid crystal molecular director stays at the two sides of this layer normal with a tilt angle of θ_r.

In the present invention, because the buffing directions **312*a***, **312*b*** (FIGS. 3A–B) of the substrates are twisted relative to each other, the molecules follow their intrinsic helical pattern in the vicinity of both substrate surfaces. It is

believed this twist angle results in a more stable alignment environment for the liquid crystal molecules and is, therefor, easier to fabricate.

The buffing strength can also play an important role in this twisted cell fabrication. In contrast to the conventional strong buffing of the alignment layer in at least some previous devices (e.g. as described in U.S. Pat. No. 5,172,257) in embodiments of the present invention, the 90° twisted structure is preferably constructed onto the alignment layers with a light or weak buffing force. Those of skill in the art will understand the distinction between light and strong buffing or rubbing and how to accomplish such buffing. The weak buffing force used in this embodiment results in a relatively weak anchoring energy at the surface. This weak anchoring force aligns the liquid crystal molecules but does not lock the molecules into the buffing directions. This provides freedom for the smectic layers to be formed within the structure. In the cell processing, it has been observed that strong buffing results in a modulator with relatively high scattering, using such 90° twist cell. This is believed to be due to the strong anchoring force distorting the smectic layer.

Light buffing also creates a pre-tilt for the liquid crystal molecules at an angle θ_0 (FIG. 4) relative to the cell walls **25**, **26**, and creates further tilt, away from the buffing direction, at an angle of θ_r. FIG. 4 illustrates this molecular alignment geometry with a twist angle of 90° between the substrates.

With this pre-tilt angle, the resultant effective cone angle is smaller than the material's cone angle. Unlike the strong surface anchoring case, (which is believed to result from strong buffing) where the liquid crystal molecules are laid in parallel to the buffing directions, weak buffing results in a high pre-tilt structure for the molecules close to the surface boundaries. In the parallel alignment case, where the buffing direction is set to 0° or 180°, the structure is generally referred as a chevron or a quasi-bookshelf. Without wishing to be bound by any theory, strong buffing is believed to bind or lock the molecules to the alignment layers and the result of the alignment quality is generally more scattered. The multi-domain texture of a liquid crystal cell resulting from strong buffing therefore, has a high transmission loss which, in some traditional configurations, is believed to be generally detrimental, particularly for telecommunications switching and similar applications.

Although a weak anchoring force (such as is achieved using weak buffing) is provided in at least some embodiments of the present invention, in other embodiments, strong buffing can be used, providing a strong anchoring force. While the weak buffing embodiment provides excellent contrast, even greater contrast can be achieved when strong anchoring (e.g. by strong buffing) is provided. In this embodiment, however, the buffing angles of the substrates are at an angle, with respect to one another, of less than 90°, preferably at about 45°, and the ferroelectric liquid crystal material has a room temperature cone angle intermediate between this angle and 0°, preferably about half the buffing angle (i.e. about 22.5° when the substrates are at 45° with respect to one another.

In view of the typical 45° tilt angle in most ferroelectric liquid crystals, a 45° twist device was tested to verify the alignment of the molecules within this twist geometry. In this case, strong and weak buffings provide similar results. This is believed to be due to the helix **27** formed between the two buffing directions, as shown in FIG. **4**. Without applied voltage, molecules splayed twisted between the two sub-

strates. With positive and negative voltages applied to the cells, molecules are switched to the two states corresponding to the respective buffing directions. With a 45° angle separation between the states, the ferroelectric liquid crystal cell forms a substantially perfect intensity modulator when $\Delta n\ d/\lambda$ is selected to provide a halfwave plate.

Optical performance of twisted ferroelectric liquid crystal cells, according to an embodiment of the present invention, is shown in FIGS. **5** and **6**, for twist angles of 45° and 90°, respectively. High contrast **512***a,b*, such as >20 dB, and preferably extremely high contrast of >30, e.g. using parallel polarizers, and >40 dB e.g. using crossed polarizers, is achieved. The high/low spectral response shown in FIGS. **5** and **6** is due to a driving voltage that is switched between two voltage states, $\pm V_{op}$. When V_{op} is greater then the threshold voltage Vth of the liquid crystal, the molecules are switched between two states with an effective cone angle qt. However, when $V_{op}<V_{th}$, analog modulation can be obtained. FIG. **7** shows the results **712** of analog modulation **714** in connection with a device according to an embodiment of the present invention. The twisted ferroelectric liquid crystal structure in this embodiment not only provides what is believed to be the highest contrast ratio that is reported to date, but also maintains analog modulation characteristics that are not available with conventional ferroelectric liquid crystal devices.

The switching time of a twisted ferroelectric liquid crystal modulator **812**, according to an embodiment of the present invention, as illustrated in FIG. **8**, has been characterized as being on the order of about 50 to 100 μsec, which is believed to be at least as low as that in conventional parallel FLC modulators.

Twisted ferroelectric liquid crystal modulators according to an embodiment of the present invention display a quasi-binary optical response. As shown in FIG. **9**, the modulator switches the corresponding state **912** when a pulse **914** is applied to the modulator. The molecules can be held steadily at their position, without relaxation, with a relatively small holding voltage, such as about 2V.

As illustrated in FIG. **10** a modulator, provided according to embodiments of the present invention includes a Twisted FLC **1012** positioned between a first polarizing element **1014** and an output birefringent element **1016**. Any of a number of commercially available polarizing elements and birefringent elements may be used. One example of an operable polarizing element is that available from Newport Optics of Irvine Calif. and sold under the trade name POLARIZER One example of an operable birefringent element is that available from Melles Geriot of Irvine Calif. and sold under the trade name BEAM DISPLACER. In use, an input lightwave **1018** is transmitted to the first polarizing element **1014**. The input lightwave may be, for example, coherent light or laser light, such as is commonly provided as output from a diode laser. The input lightwave **1018** is polarized by the first polarizing element **1014**. In the configuration depicted in FIG. **10**A, the Twisted FLC is of a type such that, when a voltage source **1022** provides a first positive voltage (e.g. 10 volts) across the Twisted FLC **1022**, the polarized lightwave **1024** emerging from the first polarizer **1014** is essentially unrotated (i.e, is rotated 0°) by the Twisted FLC **1012**. A number of voltage sources **1022** can be used. Operable voltage sources include those available from Hewlett Packard, Inc. The birefringent element **1016**, is configured to transmit the lightwave received from the twisted FLC **1012** in an unrotated state, essentially undeflected to define a first output path **1026** for the output light. In the configuration of FIG. **10**B, when the voltage source **1022** provides a second, different voltage, e.g. a negative voltage, such as −10 volts, across the twisted FLC **1022**, the polarized lightwave **1024** emerging from the first polarizer **1014** is rotated, e.g. by 90°, by the twisted FLC **1012**. The birefringent element **1016** is configured to transmit the rotated lightwave received from the twisted FLC **1012** in a deflected fashion to define a second output path **1028** for the output light, different from the first output path **1026**. In this fashion the modulator **1010** acts to change the path of lightwave **1018** in response to a change in voltage. This setup results in a structure that can provide for a polarization-dependent optical router.

One example of a system in which the modulator of the present invention can be used is a telecommunications system. FIG. **11**A depicts one example of a 1×4 (one input, four outputs) optical routing system. In FIGS. 3A through 3D, there is one light source **500** and four possible output ports **501**, **502**, **503** and **504**. The system of FIG. **11**A includes first, second, third and fourth birefringent elements **30**, **40**, **50**, **60**. The system of FIG. **11**A also includes first, second and third polarization rotators **100**, **101**, **103**, each of which may have a plurality of elements (as described below), with each element being a (separately-controllable) voltage-responsive rotator as described above. In the illustration of FIGS. **11**A–**11**D, elements which are set to provide polarization rotation are shown shaded. The system of FIG. **11**A provides an optical routing switch configured to rout an input signal **1112**, such as light from a coherent light source **500**, to output port **501**. Light **1112** is provided to a first polarizing element **30** which outputs a horizontally oriented beam **1114***a* and a vertically oriented beam **1114***b*, After the light **1112** passes through a first polarizer **30**, a first polarization rotator array **100**, which may be, for example a twisted FLC modulator component, is set (e.g. by application of an appropriate voltage from a voltage source, not shown) to rotate the vertically polarized beam **1114***b* to horizontal polarization, so that both light beams **1116***a*, **1116***b*, upon exiting the first polarization rotator array **100**, are horizontally polarized. These horizontally-polarized beams are redirected upward in the second birefringent element **40**, because they are "seen" or treated as extra-ordinary waves in this birefringent element **40**. The two beams then enter a second array of polarization rotator array **101**, which as two elements **1122***a*, **1122***b*. The second array **101** preferably comprises twisted FLC's as described above. In FIG. **11**A, the second polarization rotator array **101** is set so that, at least for the region where the light beams **1118***a*, **1118***b* are received, no polarization rotation is provided, and the light beams retain their horizontal rotation **1124***a*, **1124***b* upon exiting. The beams ten enter a third birefringent element **50**, that has a thickness twice that of the second birefringent element **40**. The horizontally polarized beams are redirected upward in the third birefringent element **50** because they are "seen" or treated as extra-ordinary waves in this birefringent element **50**. The two beams exiting the third bireflingent element **1128***a,b* continue to have the same (horizontal) polarization as they reach the third array of polarization rotators **102**. This array **102** has four pairs of pixels or sub-elements **1132***a,b*, **1134***a,b*, **1136***a,b*, **1138***a,b*, FIG. **11**E. As shown in FIG. **11**A, one of the sub-elements is set (e.g. by application of voltage) to convert one of the beams **1128** to vertical polarization so that the beam pair **1132***a*, **1132***b* becomes orthogonally polarized again. These two orthogonal beams **1132***a,b* are recombined by a fourth birefringent element **60** and exit at output port **501**.

FIG. **11**B shows the switch of FIG. **11** configured to couple light from the input port **500** to the third output port

503. In this configuration, the upper sub-element of the second polarization rotator array **101** is set (by selectable application of a voltage) to rotate the polarization of both beams **1118***a,b* by 90° sot that the beams **1124***a'*, **1124***b'* output by the second polarization array **101** have vertical polarization. The nature and configuration of the third birefringent element **50** is such that the vertically polarized input beams **1124***a'*, **1124***b'* are "seen" or treated, by the third birefringent element **50**, as ordinary waves. Therefor, no deviation occurs and the beams travel substantially straight through the third birefringent element **50**. The two vertically-polarized beams reach the third polarization array **102** which is set (by application of a voltage) to convert one beam **1128***b'* to horizontal polarization. The resulting orthogonally-polarized beams are recombined by the forth birefringent element **60** and exit at output port **503**.

FIG. **11C** shows the switch **1110** configured to couple the light from the input port **500** to the second output port **502**. In this configuration, the control states of the sub-elements **1115***a*, **1115***b* in the first polarization rotator array **100** are reversed with respect to those shown in FIGS. **11A** and **11B**, so that both beams **1116***a'*, **1116***b"* output by the first polarization rotator array **100** are vertically polarized. The vertically-polarized beams are "seen" or treated as ordinary waved by the second birefringent element **40** and therefore propagate substantially straight through birefringent element **40**. The second polarization rotator array **101** is set (by selectable application of a voltages) to rotate the polarizations of both beams by 90°, so that they become horizontally polarized. These two horizontally polarized beams **1124***a"*, **1124***b"* are "seen" or treated as extra-ordinary waves in the third birefringent element **50**, and therefore travel upward withing the third birefringent element **50**. Both beams travel to the third polarization rotator array **102** which converts one of the beams **1128***a"* to vertical polarization. The resulting orthogonally-polarized beams are recombined by the fourth birefringent element go and exit to output port **502**.

FIG. **11D** shows the switch **1110** configured to couple the input port **500** to output port **504**. In this configuration, the second polarization rotator array **101** is set to provide no polarization rotation, so that the two light beams **1118***a'"*, **1118***b'"* maintain their vertical polarizations. These two vertically-polarized beams are "seen" or treated by the third birefringent element **50** as ordinary waves, and therefore travel substantially straight through the third birefringent element **50**. The two vertically-polarized beams **1128***a'"*, **1128***b'"* travel to the third polarization rotator array **102** which is set (by selectable application of voltages) to change the polarization of one of the beams **1128***b'"* to horizontal. The resulting orthogonal beams are recombined by the fourth birefringent element **60** and exit to output port **504**.

FIG. **12** depicts one potential application of switches similar to those depicted in FIGS. **11A–11D**, to provide an optical crossconnect (OCX). The depicted OCX includes arrays of optical demultiplexers **1212***a,b,c,d*. 4×4 switches **1214***a,b,c,d* and optical multiplexers **1216***a,b,c,d*. Although, in the depicted configuration, there are four elements of each type, more or fewer elements can be used. In use, input optical fibers **1218***a,b,c,d* each carry multiple optical channels (wavelengths). Each demultiplexer **1212***a,b,c,d* separates the optical channels spatially to provide a total of 16 channels **1222** in the depicted embodiment. The 16 channels are then routed through the four 4×4 switches **1214***a,b,c,d* which are provided with control signals (selectably applied voltages) from a control unit **1224** to route the signals to provide a desired and selectable rearrangement. After the rearrangement, the channels are recombined by the multiplexers **1216***a,b,c,d* and sent to the output fibers **1226***a,b,c,d*.

In light of the above description, a number of advantages of the present invention can be seen. The present invention provides an electro-optic modulator with high contrast, fast response time, low driving voltage and which can be used in both analog and binary modes. The present invention is particularly useful in the context of optical switching and modulation devices, such as for use in telecommunications application.

A number of variations and modifications of the invention can be used. Although the ferroelectric cell has been described for use in a modulator, it can also be used for other purposes, including as an optical signal-processing unit, such as an optical correllator for image processing applications. Although the invention has been described in connection with use in a telecommunications system, the invention can be used for other purposes, including display applications, such as flat panel displays. Although an embodiment of the invention provides light buffing on each alignment layer, it is possible to provide heavier buffing on one layer than on the other. Although buffing with silk has been described, alignment directions can also be created by other techniques such as angle SiO evaporation.

What is claimed is:

1. A twisted non-surface-stabilized ferroelectric liquid crystal electro-optic modulator, comprising:

a first assembly having a first electrode and a first buffed alignment layer having a first buffing direction, for aligning a first adjacent portion of said ferroelectric liquid crystal;

a second assembly having a second electrode and a second buffed alignment layer, having a second buffing direction at an angle of from about 44° to about 90° from said first buffing direction, for aligning a second adjacent portion of said ferroelectric liquid crystal; and

ferroelectric liquid crystal material positioned between said first and second assembly, in contact with said first and second buffed alignment layers, said ferroelectric liquid crystal material having a room temperature cone angle between about 20° and about 25°, said first buffed alignment layer and said second buffed alignment layer providing an anchoring energy, wherein said ferroelectric liquid crystal material is provided with a pre-tilt angle of between about 3 degrees and about 7 degrees; and

a voltage source configurable for providing an applied voltage across said first and second electrodes.

2. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim 1, wherein said modulator is constructed such that said anchoring energy is a weak anchoring energy wherein molecules of said liquid crystal material adjacent said first and second buffed alignment layers are non-parallel with said buffing directions.

3. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim 1, further comprising parallel input and output polarizers, and wherein said modulator, when actuated, provides contrast of at least about 30 dB.

4. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim 1, further comprising crossed input and output polarizers, and wherein said modulator, when actuated, provides contrast of at least about 20 dB.

5. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim 1, wherein said modulator provides a switching time of less than about 100 μsec.

6. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim 1, wherein said modulator provides a switching time of less than about 50 μsec.

7. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim **1**, wherein said modulator is provided with an effective cone angle less than the intrinsic cone angle of said ferroelectric liquid crystal material.

8. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim **1**, wherein said modulator is provided with an optical transmission loss of less than about 20%.

9. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim **1**, wherein said modulator exhibits bimodal modulation when the magnitude of said applied voltage exceeds a first threshold voltage, and exhibits analog modulation related to the voltage magnitude, when said magnitude of said applied voltage is less than said threshold voltage.

10. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim **1**, wherein said modulator changes state when a voltage pulse is applied to said modulator.

11. A twisted ferroelectric liquid crystal electro-optic modulator, as claimed in claim **1**, wherein following a change in state, the voltage needed to maintain molecules of said ferroelectric liquid crystal in position is less than about 2V.

12. A non-surface stabilized twisted ferroelectric liquid crystal electro-optic modulator, comprising:

a first assembly having first electrode means and first alignment means, having a first direction, for aligning a first adjacent portion of ferroelectric liquid crystal;

a second assembly having second electrode means and second alignment means, having a second direction at an angle of from about 44° to about 90° from said first direction, for aligning a second adjacent portion of ferroelectric liquid crystal; and

ferroelectric liquid crystal material positioned between said first and second assemblies, in contact with said first and second alignment means, said ferroelectric liquid crystal material having a room temperature cone angle between about 20° and about 25°, said first alignment means and said second alignment means including means for providing an anchoring energy wherein molecules of said liquid crystal material adjacent said first and second alignment means are non-parallel with said first and second directions, respectively wherein said ferroelectric liquid crystal material is provided with a pre-tilt angle of between about 3 degrees and about 7 degrees, and

means for providing an applied voltage across said first and second electrodes.

13. A twisted ferroelectric liquid crystal elecro-optic modulator as claimed in claim **12** wherein said means for providing an anchoring energy is a means for providing a weak anchoring energy.

14. A Twisted ferroelectric liquid crystal eletro-optic modulator as claimed in claim **12** wherein said means for providing an anchoring energy is a means for providing a strong anchoring energy.

15. A telecommunication switching system, comprising:

at least a first modulator having ferroelectric crystal material wherein said ferroelectric liquid crystal material is provided with a pre-tilt angle of between about 3 degrees and about 7 degrees and wherein said ferroelectric liquid crystal material has as an intrinsic property a cone angle of about 22° between lightly buffed first and second alignment layers, wherein a buffing direction of said first alignment layer forms an angle of about 90° to 44° with a buffing direction of said second alignment layer;

a light source for providing light to said first modulator;

a controllable voltage source wherein said light follows a first path when said voltage source provides a first voltage to said ferroelectric crystal material and a second path when said voltage source provides a second voltage to said ferroelectric crystal material.

16. A telecommunication switching system, comprising:

at least a first modulator having ferroelectric crystal material between strongly buffed first and second alignment layers defining first and second buffing directions which are about 45° apart, wherein said ferroelectric crystal material has as an intrinsic property a cone angle of about 22°;

a light source for providing light to said first modulator;

a controllable voltage source wherein said light follows a first path when said voltage source provides a first voltage to said ferroelectric crystal material and a second path when said voltage source provides a second voltage to said ferroelectric crystal material.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,141,076
DATED : October 31, 2000
INVENTOR(S) : Liu et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

After the title by inserting the following:

GOVERMENT INTERESTS
The invention was made with Goverment support under DARPA II: DAH01-97-C-R308 awarded by U.S. Army Missile Command, AMSMI-AC-CRAY, Redstone Arsenal, AL 35898. The Goverment has certain rights in the invention. --

Signed and Sealed this

Thirtieth Day of October, 2001

Attest:

Nicholas P. Godici

NICHOLAS P. GODICI

Attesting Officer *Acting Director of the United States Patent and Trademark Office*

APPENDIX C

A copy of passages from Ferroelectric and Antiferroelectric Liquid Crystals, by Sven T. Lagerwall (1999).

Sven T. Lagerwall

Ferroelectric and Antiferroelectric Liquid Crystals

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This book was carefully produced. Nevertheless, author and publisher do not warrant the information contained therein to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

Cover picture:
Zigzag defects in a smectic C*.
Courtesy of Noel Clark and Tom Rieker.

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way between 1 and 2), which gives a contribution to the threshold for the process. Generally speaking, the bulk switching on either side of the chevron interface preceeds the switching in the interface. The latter contributes to the latching and thus to the bistability.

As seen from Fig. 96b, the switching process is unambiguous as regards the motion of ***n*** and ***P*** (sterically bound to ***n***): on the upper side of the chevron, ***P*** rotates counterclockwise, on the lower side it rotates clockwise when we switch from 1 to 2; everything turns around in the reverse switching direction. This explains why there are no twist and antitwist domains like the ones observed in twisted nematics prior to the time when chiral dopants were added in order to promote a certain twist sense.

So far we have described the switching concentrating on the chevron interface, completely disregarding what could happen at the two bounding (electrode) surfaces. In fact, if the anchoring condition on the surfaces is very strong, switching between up and down states of polarization will only take place at the chevron interface. At high voltage this will more or less simultaneously take place in the whole sample. At low voltage it will be possible to observe the appearance of down domains as "holes" created in an up background, or vice versa, in the shape of so-called boat domains (see Fig. 105) in the chevron interface (easily localized to this plane by optical microscopy). The walls between up and down domains have the configuration of strength one (or 2π) disclinations in the ***P*** field.

It should be pointed out that the uniqueness of director rotation during the switching process is not a feature related to the chevron per se, but only to the fact that the chevron creates a certain ***P***-tilt at the chevron interface. If the boundary conditions of the glass surfaces involved a similar ***P***-tilt, this will have the same effect.

A glance at Fig. 97 reveals another important consequence of the chevron structure. As ***P*** is not along ***E*** (applied field) there will always be a torque ***P***×***E*** tending to straighten up the chevron to an almost upright direction. Especially in antiferroelectric liquid crystals, which are used with very high *P* values, this torque is sufficiently strong for almost any applied field, for instance normal addressing pulses, to raise and keep the structure in a so-called quasi-bookshelf structure (QBS) under driving conditions. In ferroelectric liquid crystals, presently with considerably lower *P* values, the same effect was previously employed to ameliorate contrast and

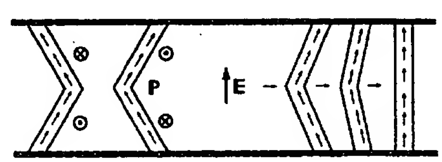

Figure 97. The fact that even after switching the polarization ***P*** is not entirely in the direction of the applied field will tend to raise the chevron structure into a more upright position, so decreasing the effective δ but breaking up the layers in a perpendicular direction. This gives a characteristic striped texture from the newly created, locked-in defect network.

threshold properties, by conditioning the chevron FLC to QBS FLC by the application of AC fields [169]. The effect on the switching threshold can be extracted from Fig. 96. When the chevron structure is straightened up, δ decreases and the two cones overlap more and more, leading to an increasing distance between 1 and 2, as well as further compression of the tilt angle θ in order to go between 1 and 2. The threshold thus increases, in agreement with the findings of the Philips (Eindhoven) group. On the other hand, this straightening up to QBS violates the conservation of smectic layer thickness d_C, which will lead to a breaking up of the layers in a direction perpendicular to the initial chevrons, thus causing a buckling out of the direction running perpendicular to the paper plane of Fig. 97.

8.4 Analog Grey Levels

As we just pointed out, in the chevron structure the polarization is no longer collinear with the external field. This can be used (for materials with a high value of P) to straighten up the chevron into a so-called quasi-bookshelf structure, combining some of the advantages from both types of structure. For instance, it can combine a high contrast with a continuous gray scale.

How to produce analog gray levels in an SSFLC display is perhaps not so evident, because the electrooptic effect which we have essentially dealt with so far offers two optical states, hence it is digital. Nevertheless, the shape of the hysteresis curve reveals that there must be small domains with a slightly varying threshold, in some analogy with the common ferromagnetic case. Normally, however, the flank of the curve is not sufficiently smeared out to be controlled and to accommodate more than a few levels. Curve I of Fig. 98 shows the transmission–voltage characteristics for a typical SSFLC cell with the layers in the chevron configuration [165]. The threshold voltage is fairly low, as well as the achievable transmission in the bright state, leading to a low brightness–contrast ratio. The position and sharpness of the threshold curve reflect the relatively large and constant chevron angle δ_0 in the sample. If a low frequency AC voltage of low amplitude (6–10 V) is applied, the smectic layers will be straightened up towards the vertical due to the $P-E$ coupling, so that the local polarization vector increases its component along the direction of the field. This field action, which requires a sufficiently high value of P, breaks the layer ordering in the plane of the sample and introduces new defect structures, which are seen invading the sample. The result is that the chevron angle δ is reduced, on average, and the threshold smeared out, as shown by curve II. Lower δ means a larger switching angle (and higher threshold), and thus higher transmission. Still higher transmission can be achieved by an additional treatment at a somewhat higher voltage (±25 V), giving threshold curve III, corresponding to a new distribution around a lower δ-value and a microdomain texture on an even finer scale.

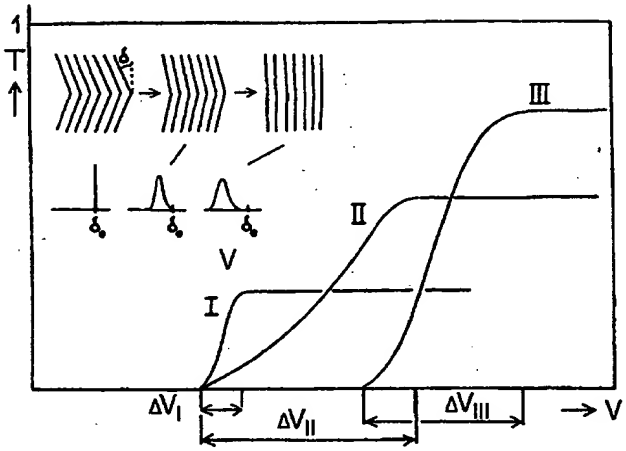

Figure 98. Amplitude-controlled gray scale in SSFLC. The chevron structure is transformed to a quasi-bookshelf (QBS) structure by external field treatment. In addition to giving gray shades, the QBS structure increases the brightness and the viewing angle. This method of producing gray levels was developed by the Philips (Eindhoven) group, who called it the "texture method".

The actual switching threshold is a complicated quantity, not fully understood (no successful calculation has been presented so far), and usually expressed as a voltage–time area threshold for the switching pulse. For a given pulse length it is, however, reasonable that the amplitude threshold increases according to Fig. 98 when the average value of δ decreases. There are at least two reasons for this, as illustrated by Fig. 96. First, it is seen that the distance between the two positions n_1 and n_2 in the chevron kink level (which acts as a third, internal surface), as well as the corresponding positions at the outer surfaces and in between, increase when δ decreases. It would therefore take a longer time to reach and pass the middle transitory state, after which the molecules would latch in their new position. In addition, it is seen that the local deformation of the cone i.e., a decrease of the tilt angle θ, which is necessary to actuate the transition from n_1 to n_2, increases when δ decreases. (A paradox feature of this deformation model is that it works as long as $\delta \neq 0$, whereas $\delta = 0$ gives no deformation at all – but also no chevron – at the chevron kink level.)

The smectic layer organization corresponding to curves II and III of Fig. 98 is generally characterized as a quasi-bookshelf (QBS) structure, denoting that the layers are essentially upright with only a small chevron angle. The QBS structure has a very large gray scale capacity. This might, however, possibly not be utilized to advantage in a passively driven display (as it can in the AFLC version). Its drawback in this respect is that the shape of the threshold curve is temperature-dependent, which leads to the requirement of a very well-controlled and constant temperature over the whole area of a large display. Furthermore, the QBS structure is a metastable state. Finally, the microdomain control of gray shades requires an additional sophistication in the electronic addressing: in order to achieve the same transmission level for a given applied amplitude, the inherent memory in the microdomains has to be deleted, which is done by a special blanking pulse. Using this pulse, the display is reset to the same starting condition before the writing pulse arrives. As a result of these features, it is not clear whether the microdomain method will be successfully applied